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Multiplicity Fluctuations in Au+Au Collisions at RHIC

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Abstract

The preliminary data of the PHENIX collaboration for the scaled variances of charged hadron multiplicity fluctuations in Au+Au at $\sqrt{s} = 200$ GeV are analyzed within the model of independent sources. We use the HSD transport model to calculate the participant number fluctuations and the number of charged hadrons per nucleon participant in different centrality bins. This combined picture leads to a good agreement with the PHENIX data and suggests that the measured multiplicity fluctuations result dominantly from participant number fluctuations. The role of centrality selection and acceptance is discussed separately.

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The event-by-event fluctuations in high energy nucleus-nucleus (A+A) collisions (see e.g., the reviews [1, 2]) are expected to provide signals of the transition between different phases (see e.g., Refs. [3, 4]) and the QCD critical point [5]. In the present letter we study the charged multiplicity fluctuations in Au+Au collisions at RHIC energies. The preliminary data of the PHENIX collaboration [6] at $\sqrt{s} = 200$ GeV are analyzed within the model of independent sources while employing the microscopic Hadron-String-Dynamics (HSD) transport model [7, 8] to define the centrality selection and to calculate the properties of hadron production sources.

The centrality selection is an important aspect of fluctuation studies in A+A collisions. At the SPS fixed target experiments the samples of collisions with a fixed number of projectile participants N_P^{proj} can be selected to minimize the participant number fluctuations in the sample of collision events. This selection is possible due to a measurement of the number of nucleon spectators from the projectile, N_S^{proj} , in each individual collision by a calorimeter which covers the projectile fragmentation domain. However, even in the sample with $N_P^{proj} = const$ the number of target participants fluctuates considerably. In the following the variance, $Var(n) \equiv \langle n^2 \rangle - \langle n \rangle^2$, and scaled variance, $\omega \equiv Var(n)/\langle n \rangle$, where n stands for a given random variable and $\langle \dots \rangle$ for event-by-event averaging, will be used to quantify fluctuations. In each sample with $N_P^{proj} = const$ the number of target participants fluctuates around its mean value, $\langle N_P^{targ} \rangle = N_P^{proj}$, with the scaled variance ω_P^{targ} . Within the HSD and UrQMD transport models it was found in Ref. [9] that the fluctuations of N_P^{targ} strongly influence the charged hadron fluctuations. The constant values of N_P^{proj} and fluctuations of N_P^{targ} lead also to an asymmetry between the fluctuations in the projectile and target hemispheres. The consequences of this asymmetry depend on the A+A dynamics as discussed in Ref. [10].

In Au+Au collisions at RHIC a different centrality selection is used. There are two kinds of detectors which define the centrality of Au+Au collision, Beam-Beam Counters (BBC) and Zero Degree Calorimeters (ZDC). At the c.m. pair energy $\sqrt{s} = 200$ GeV, the BBC measure the charged particle multiplicity in the pseudorapidity range $3.0 < |\eta| < 3.9$, and the ZDC – the number of neutrons with $|\eta| > 6.0$ [6]. These neutrons are part of the nucleon spectators. Due to technical reasons the neutron spectators can be only detected by the ZDC (not protons and nuclear fragments), but in both hemispheres. The BBC distribution will be used in the HSD calculations to divide Au+Au collision events into 5% centrality samples. HSD does not specify different spectator groups – neutrons, protons, and nuclear fragments

such that we can not use the ZDC information. In Fig. 1 (left) the HSD results for the BBC distribution and centrality classes in Au+Au collisions at $\sqrt{s} = 200$ GeV are shown. We find a good agreement between the HSD shape of the BBC distribution and the PHENIX data [6]. The experimental estimates of $\langle N_P \rangle$ for different centrality classes are based on the Glauber model. These estimates vary by less than 0.5% depending on the shape of the cut in the ZDC/BBC space or whether the BBC alone is used as a centrality measure [6]. Note, however, that the HSD $\langle N_P \rangle$ numbers are not exactly equal to the PHENIX values. It is also not obvious that different definitions for the 5% centrality classes give the same values of the scaled variance ω_P for the participant number fluctuations.

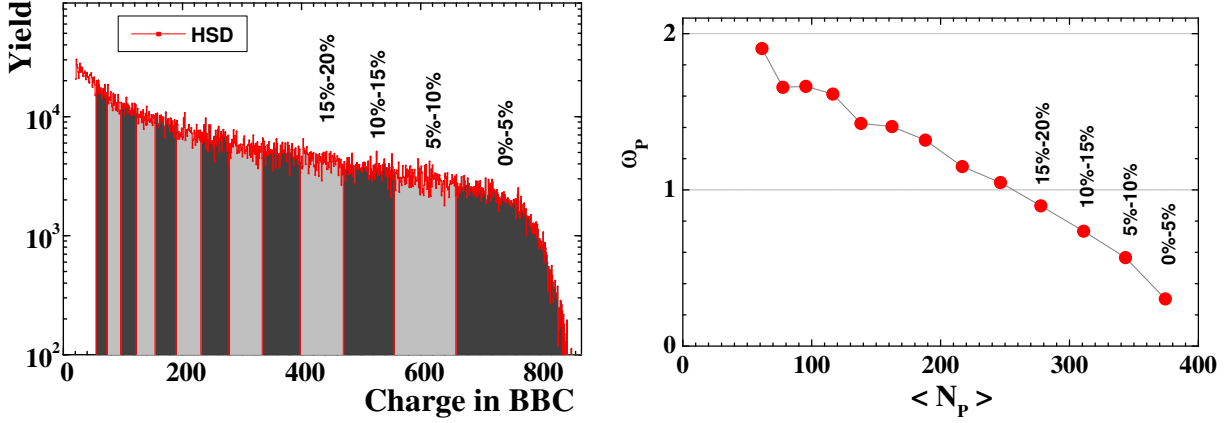


FIG. 1: HSD model results for Au+Au collisions at $\sqrt{s} = 200$ GeV. *Left*: Centrality classes defined via the BBC distribution. *Right*: The average number of participants, $\langle N_P \rangle$, and the scaled variance of the participant number fluctuations, ω_P , calculated for the 5% BBC centrality classes.

Defining the centrality selection via the HSD transport model (which is similar to the BBC in the PHENIX experiment) we calculate the mean number of nucleon participants, $\langle N_P \rangle$, and the scaled variance of its fluctuations, ω_P , in each 5% centrality sample. The results are shown in Fig. 1, right. The Fig. 2 (left) shows the HSD results for the mean number of charged hadrons per nucleon participant, $n_i = \langle N_i \rangle / \langle N_P \rangle$, where the index i stands for “−”, “+”, and “ch”, i.e negatively, positively, and all charged final hadrons. Note that the centrality dependence of n_i is opposite to that of ω_P : n_i increases with $\langle N_P \rangle$, whereas ω_P decreases.

The PHENIX detector accepts charged particles in a small region of the phase space with pseudorapidity $|\eta| < 0.26$ and azimuthal angle $\phi < 245^\circ$ and the p_T range from 0.2 to 2.0

GeV/c [6]. The fraction of the accepted particles $q_i = \langle N_i^{acc} \rangle / \langle N_i \rangle$ calculated within the HSD model is shown in the r.h.s. of Fig. 2. According to the HSD results only $3 \div 3.5\%$ of charged particles are accepted by the mid-rapidity PHENIX detector.

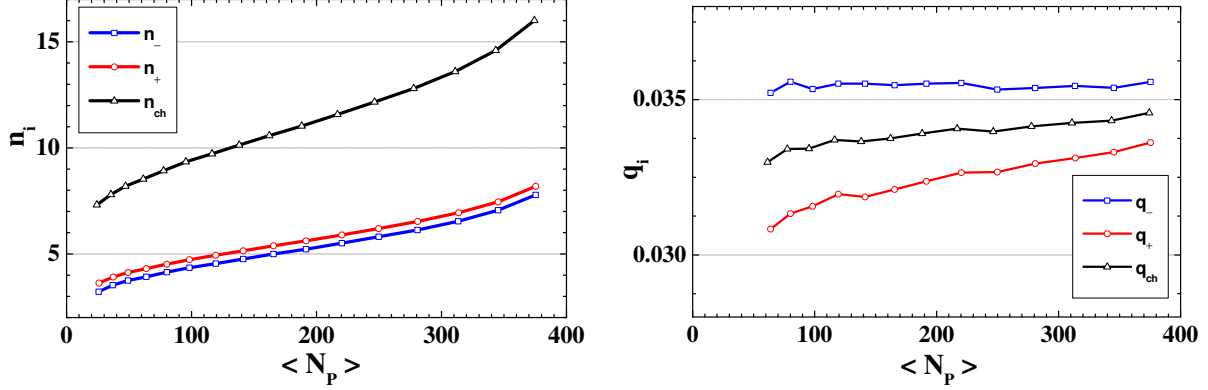


FIG. 2: HSD results for different BBC centrality classes in Au+Au collisions at $\sqrt{s} = 200$ GeV. *Left:* The mean number of charged hadrons per participant, $n_i = \langle N_i \rangle / \langle N_P \rangle$. *Right:* The fraction of accepted particles, $q_i = \langle N_i^{acc} \rangle / \langle N_i \rangle$.

To estimate the role of the participant number event-by-event fluctuations we use the model of independent sources (see e.g., Refs [1, 9, 10]),

$$\omega_i = \omega_i^* + n_i \omega_P . \quad (1)$$

The first term in the r.h.s. of Eq. (1) corresponds to the fluctuations of the hadron multiplicity from one source, and the second term, $n_i \omega_P$, gives additional fluctuations due to the fluctuations of the number of sources. As usually, we have assumed that the number of sources is proportional to the number of nucleon participants. The value of n_i in Eq. (1) is then the average number of i 'th particles per participant, $n_i = \langle N_i \rangle / \langle N_P \rangle$. We also assume that nucleon-nucleon collisions define the fluctuations ω_i^* from a single source. To calculate the fluctuations ω_i^{acc} in the PHENIX acceptance we use the acceptance scaling formula (see e.g., Refs. [1, 9, 10]):

$$\omega_i^{acc} = 1 - q_i + q_i \omega_i , \quad (2)$$

where q_i is the fraction of the accepted i 'th hadrons by the PHENIX detector. Using Eq. (1) for ω_i one finds,

$$\omega_i^{acc} = 1 - q_i + q_i \omega_i^* + q_i n_i \omega_P . \quad (3)$$

The HSD results for ω_P (Fig. 1, right), n_i (Fig. 2, left), q_i (Fig. 2, right), together with the HSD nucleon-nucleon values, $\omega_-^* = 3.0$, $\omega_+^* = 2.7$, and $\omega_{ch}^* = 5.7$ at $\sqrt{s} = 200$ GeV, define completely the results for ω_i^{acc} according to Eq. (3). We find a surprisingly good agreement of the results given by Eq. (3) with the PHENIX data shown in Fig. 3. Note that the centrality dependence of ω_i^{acc} stems from the product, $n_i \cdot \omega_P$, in the last term of the r.h.s. of Eq. (3).

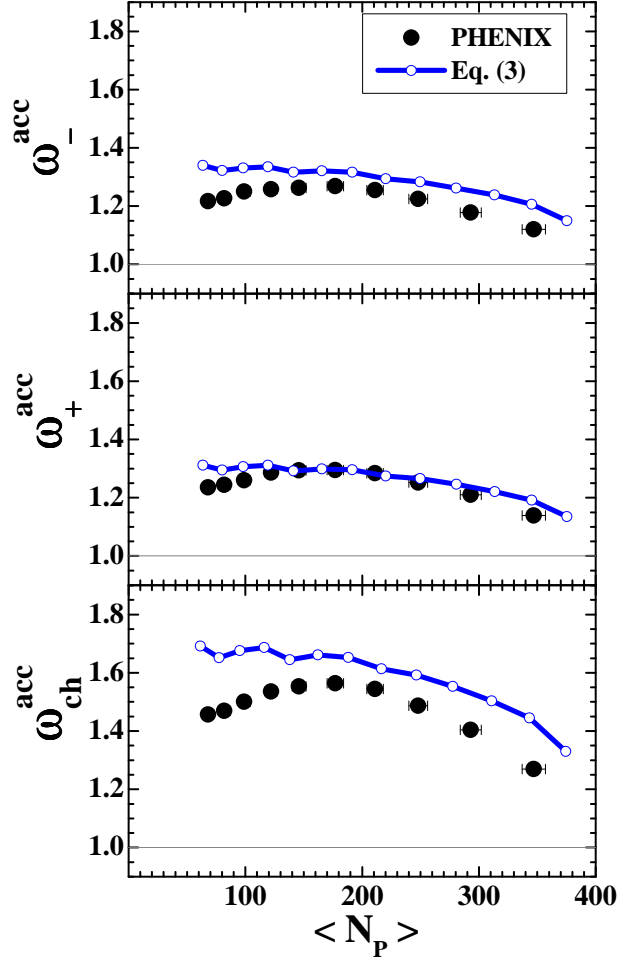


FIG. 3: The scaled variance of charged particle fluctuations in Au+Au collisions at $\sqrt{s} = 200$ GeV with the PHENIX acceptance. The circles are the PHENIX data [6] while the open points (connected by the solid line) correspond to Eq. (3) with the HSD results for ω_P , n_i , and q_i .

In summary, the preliminary PHENIX data [6] for the scaled variances of charged hadron multiplicity fluctuations in Au+Au collisions at $\sqrt{s} = 200$ GeV have been analyzed within the model of independent sources. Assuming that the number of hadron sources are proportional to the number of nucleon participants, the HSD transport model was used to calculate

the scaled variance of participant number fluctuations, ω_P , and the number of i 'th hadrons per nucleon accepted by the mid-rapidity PHENIX detector, $q_i n_i$, in different Beam-Beam Counter centrality classes. The HSD model for nucleon-nucleon collisions was also used to estimate the fluctuations from a single source, ω_i^* . We find that this model description is in a good agreement with the PHENIX data [6]. In different (5%) centrality classes ω_P goes down and $q_i n_i$ goes up with increasing $\langle N_P \rangle$. This results in non-monotonic dependence of ω_i^{acc} on $\langle N_P \rangle$ as seen in the PHENIX data.

We conclude that both qualitative and quantitative features of the centrality dependence of the fluctuations seen in the present PHENIX data are the consequences of participant number fluctuations. To avoid a dominance of the participant number fluctuations one needs to analyze most central collisions with a much more rigid ($\leq 1\%$) centrality selection. The statistical model then predicts $\omega_{\pm} < 1$ [11], whereas the HSD transport model predicts the values of ω_{\pm} much larger than unity at $\sqrt{s} = 200$ GeV [12]. To allow for a clear distinction between these predictions it is mandatory to enlarge the acceptance of the mid-rapidity detector up to about 10% (see the discussion in Ref. [12]).

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